HIGH FREQUENCY COMMUNICATION SYSTEMS

Lecture 3

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- Antennas and Radiation
- Potential Functions
- Antenna Characteristics

- A distribution of currents and charges can generate and radiate electromagnetic fields
  - The distribution is typically localised in a region of space
  - As an example, a simple wire can act as an *antenna*
- We are interested in determining the electromagnetic fields in space, given a current distribution

- Antennas are most widely used for wireless communications
- Modern antenna invention is attributed to Heinrich Hertz (1887)
  - Radio system was developed by Guglielmo Marconi (1897)
- Due to the *duality* principle, an antenna can also act as a receiver to EM radiation

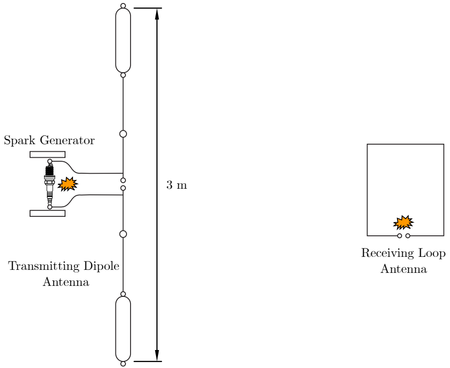

Figure 1: The Hertz's invention

- We need a disturbance in the EM fields
  - Most commonly, this is caused by a time-varying electric current
- The disturbance also depends on the nature of the antenna
  - For a wire antenna, the discontinuities at the ends cause radiation

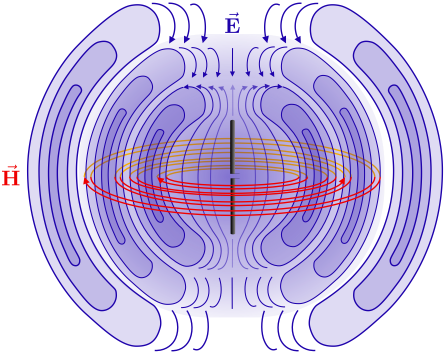

Figure 2: Antenna Radiation Mechanism

- There are mainly two ways to find the radiated fields from a given current distribution

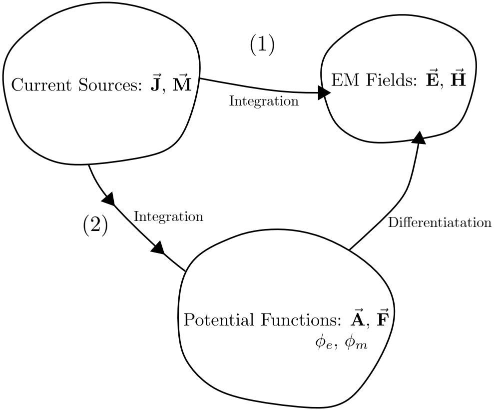

Figure 3: Two ways to find the radiated EM fields

- Solving EM fields directly using the Maxwell's equations is often very difficult, especially in the spatial domain
- The introduction of scalar ($\vec{\phi}$) and vector $\vec{\mathbf{A}}$ potential functions simplify the process
- We start from the fact:
  - Magnetic field is divergence-less ($\boldsymbol{\nabla} \cdot \vec{\mathbf{B}} = 0$). We can therefore, say that:

$$\boldsymbol{\nabla} \cdot \boldsymbol{\nabla} \times \vec{\mathbf{A}} \equiv 0$$

$$\Rightarrow \vec{\mathbf{H}} = \frac{1}{\mu} \boldsymbol{\nabla} \times \vec{\mathbf{A}}$$

We can write the Ampere's law as:

$$\boldsymbol{\nabla} \times \vec{\mathbf{E}} = -j\omega\mu\vec{\mathbf{H}} = j\omega\boldsymbol{\nabla} \times \vec{\mathbf{A}}$$

$$\boldsymbol{\nabla} \times \left(\vec{\mathbf{E}} + j\omega\vec{\mathbf{A}}\right) = 0$$

Knowing that the $\nabla \times (-\nabla\phi) \equiv 0$, we set:

$$\vec{\mathbf{E}} + j\omega\vec{\mathbf{A}} = -\nabla\phi$$
$$\vec{\mathbf{E}} = -\nabla\phi - j\omega\vec{\mathbf{A}}$$

- ϕ is the electric scalar potential and its a function of position.
- If we know $\vec{\mathbf{A}}$ and ϕ, we can find $\vec{\mathbf{E}}$ and $\vec{\mathbf{H}}$

- We still need to figure out how to find the potentials, $\vec{\mathbf{A}}$ and ϕ for a given current density $\vec{\mathbf{J}}$.
- For this we move back to the Maxwell's equations and find a relationship

$$\begin{aligned}
\boldsymbol{\nabla} \times \vec{\mathbf{H}} &= j\omega\varepsilon\vec{\mathbf{E}} + \vec{\mathbf{J}} \\
\boldsymbol{\nabla} \times \left(\boldsymbol{\nabla} \times \vec{\mathbf{A}}\right) &= j\omega\mu\varepsilon\vec{\mathbf{E}} + \mu\vec{\mathbf{J}} \\
\boldsymbol{\nabla} \times \boldsymbol{\nabla} \times \vec{\mathbf{A}} &= j\omega\mu\varepsilon\left(-j\omega\vec{\mathbf{A}} - \boldsymbol{\nabla}\phi\right) + \mu\vec{\mathbf{J}}
\end{aligned}$$

Continuing and using the vector identity,
$\boldsymbol{\nabla} \times \boldsymbol{\nabla} \times \vec{\mathbf{A}} = \boldsymbol{\nabla}\left(\boldsymbol{\nabla} \cdot \vec{\mathbf{A}} - \nabla^2 \vec{\mathbf{A}}\right)$ and rearranging, we get,

$$\nabla^2 \vec{\mathbf{A}} + \omega^2 \mu\varepsilon \vec{\mathbf{A}} = -\mu \vec{\mathbf{J}} + \boldsymbol{\nabla}\left(\boldsymbol{\nabla} \cdot \vec{\mathbf{A}} + j\omega\mu\varepsilon\phi\right)$$

The solution is complete by defining $\vec{\mathbf{A}}$ in terms of ϕ through the Lorentz gauge,

$$\boldsymbol{\nabla} \cdot \vec{\mathbf{A}} = -j\omega\mu\varepsilon\phi$$

- Given an electric current density $\vec{\mathbf{J}}$
- Solve for the magnetic vector potential $\vec{\mathbf{A}}$
  - Solve for $\vec{\mathbf{E}}$ and $\vec{\mathbf{H}}$

There are some assumptions in this method, namely:

- The space is homogeneous (only one material)
- The magnetic current density $\vec{\mathbf{M}}$ is zero.

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